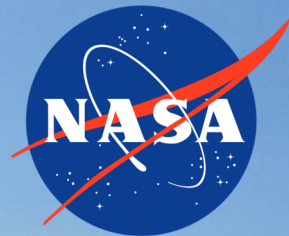




TREX

Toolbox for Research & Exploration



TOOLBOX FOR RESEARCH AND EXPLORATION (TREX):

Autonomous rover-based science in the field

Eldar Z. Noe Dobrea
and the
SSERVI-TREX team

Toolbox for Research and Exploration (TREX)

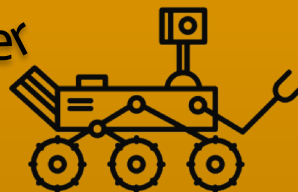
- TREX (SSERVI node) aims to decrease risk to future missions by improving operational efficiency and science yield.
- TREX focuses on spectral characterization of fine particles and the potential resources they may harbor; as well as automated exploration of fine-grained surfaces.
- Four Themes:
 1. Lab studies,
 2. Moon studies,
 3. Small bodies studies, and
 4. Field experiments
- Here, we discuss our plans for field experiments,
 - focus delegating mission planning, data collection, analysis, and decision-making to an automated robotic explorer

Premise

- Today's robotic exploration is centered around a tight operator/robot iterative process in which a team of operators carefully instructs the robot on navigation and target selection.
- Data rates are low and hence a complete assessment of the field area is rare, and activities are therefore decided upon based on limited knowledge of the site.
- Hence, the process is slow and important observations may be missed.

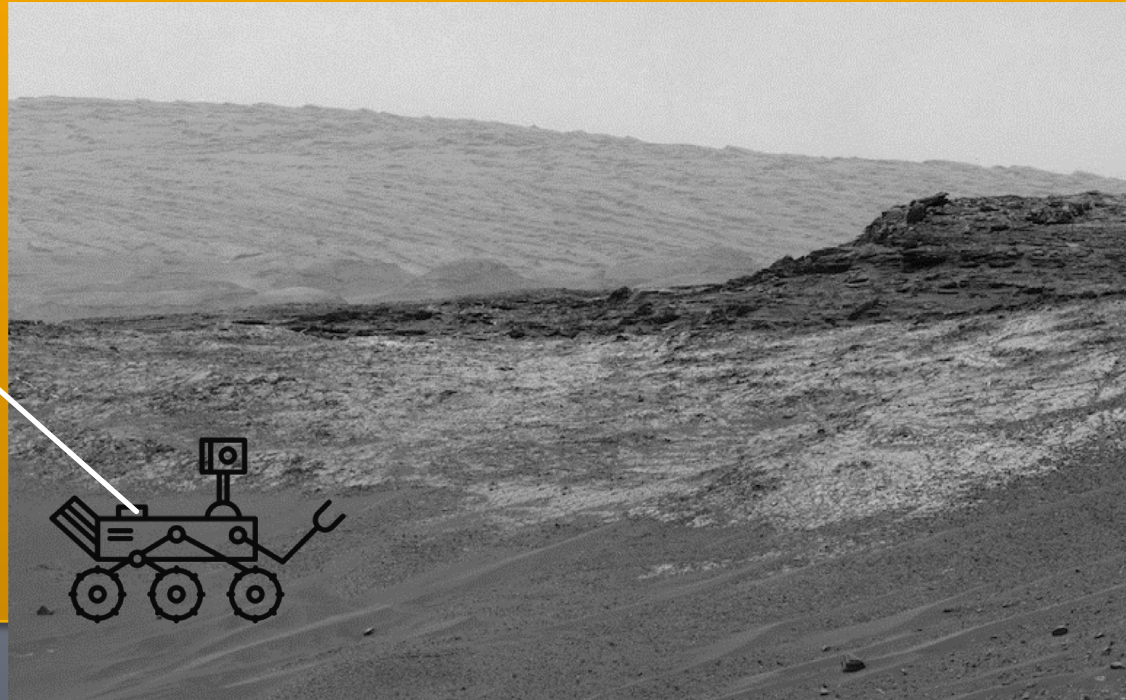
Today's robotic exploration is centered around a tight operator/robot iterative process in which a team of operators carefully instructs the robot on navigation and target selection.

Acquire full panorama – single filter





1b. Panorama





Let's acquire color
data of a few
morphologically
representative
locations

Analysis and interpretation

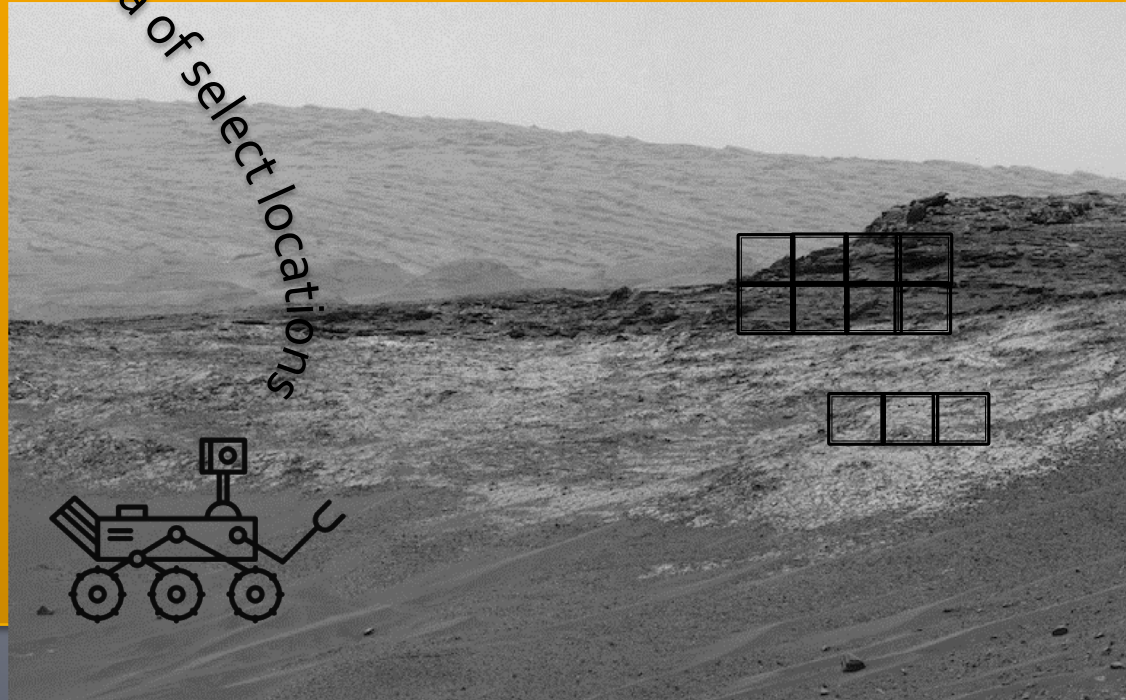
Data rates are low → complete
assessment of the field area is
rare, and activities are decided
upon based on limited
knowledge of the site.

Team telecon and decision-
making

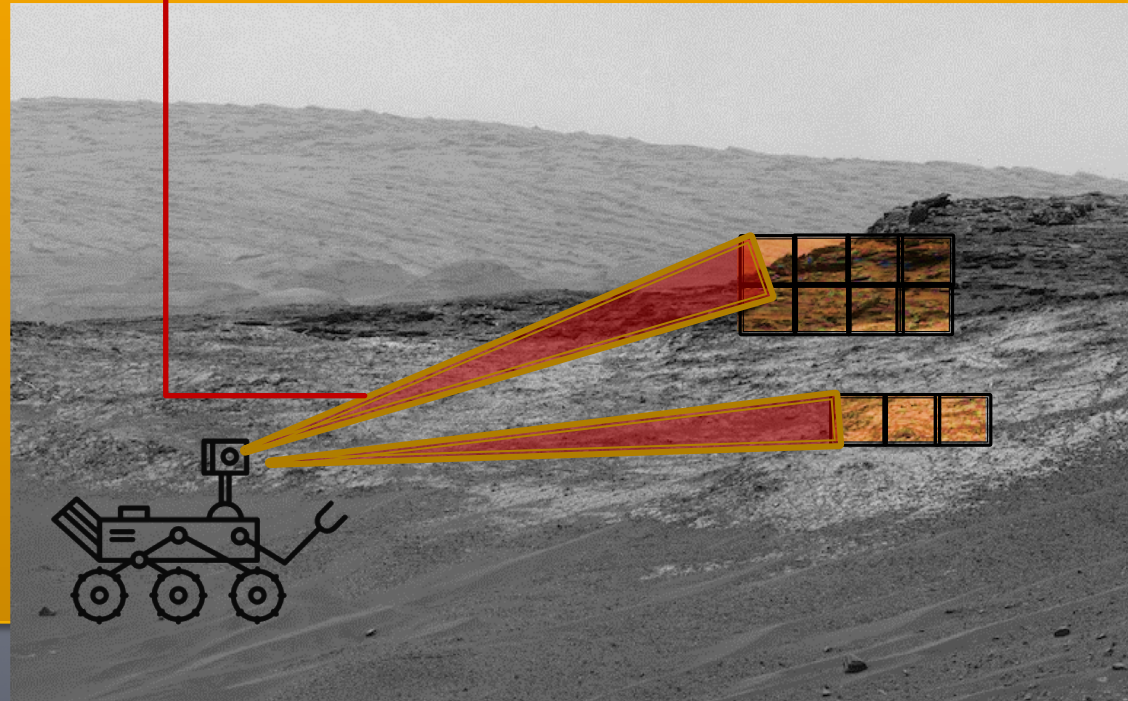


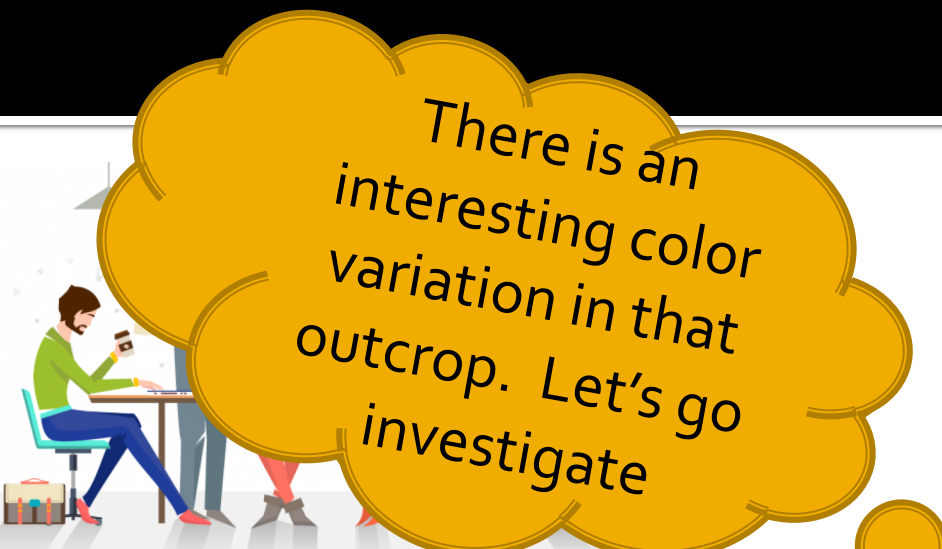


Acquire multispectral data of select locations



Multispectral observations





There is an interesting color variation in that outcrop. Let's go investigate

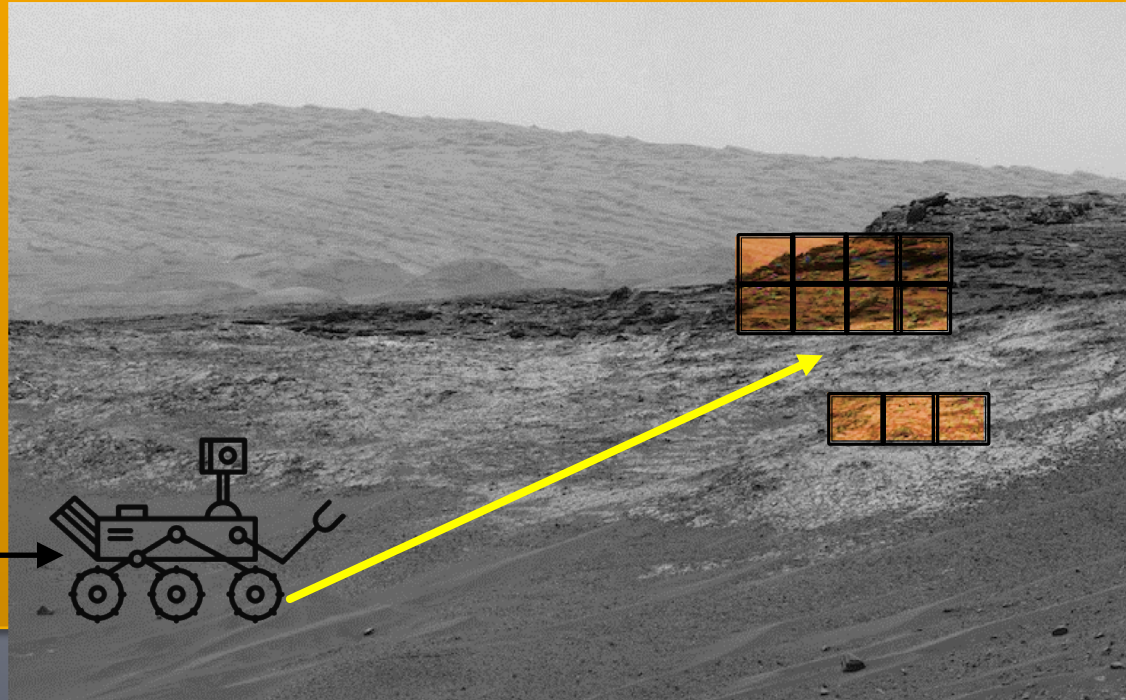
Hence, the process is slow ...



...and important observations may be missed.



Drive to
Selected location



New paradigm

- We propose a different paradigm
 - rover activities are not uniquely prescribed by each iteration of commands sent from the operator,
 - open-ended and responsive to ongoing observations, even without iterative feedback from an operator.
1. Scientist/operator provides the rover with a set of hypotheses and associated measurable observables.
 2. The autonomous rover performs traverses and observations based on previously acquired knowledge and assesses the terrain in the context of these hypotheses.
 3. Periodically, or when the robotic explorer encounters something that falls outside the realm of expected observables, the robotic explorer contacts the operator to offer updates or request new directions.

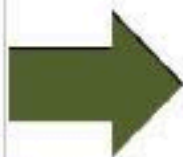
Scientist

Robot

Initial,
revised
science
hypothesis
maps



Explicit
commands,
constraints



Pool of
hypothesis
maps

Resampling

Map
probability
weights

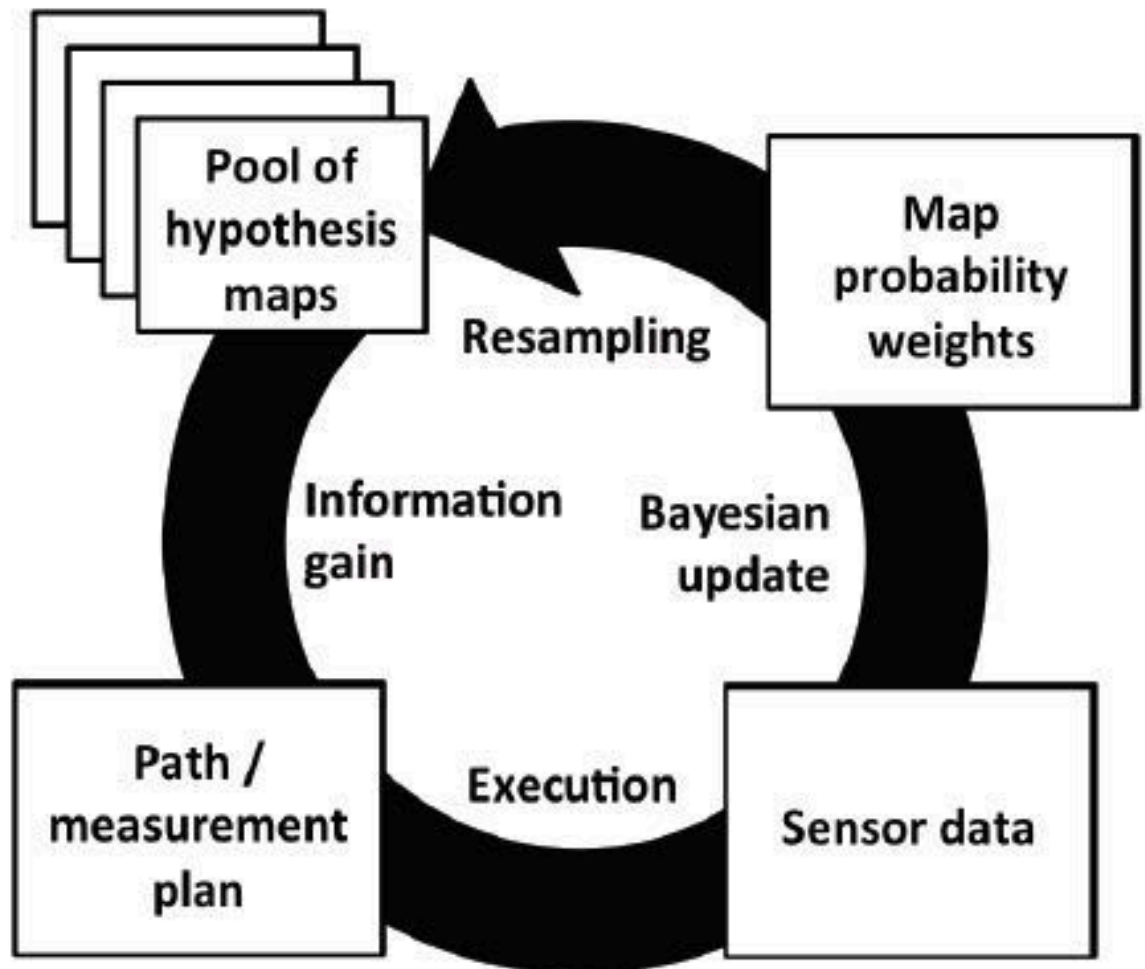
Information
gain

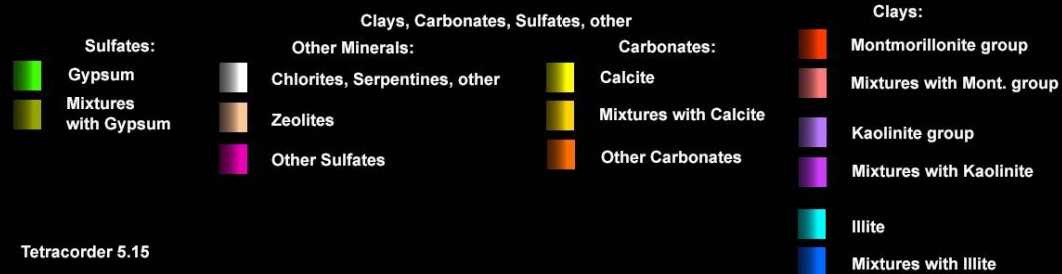
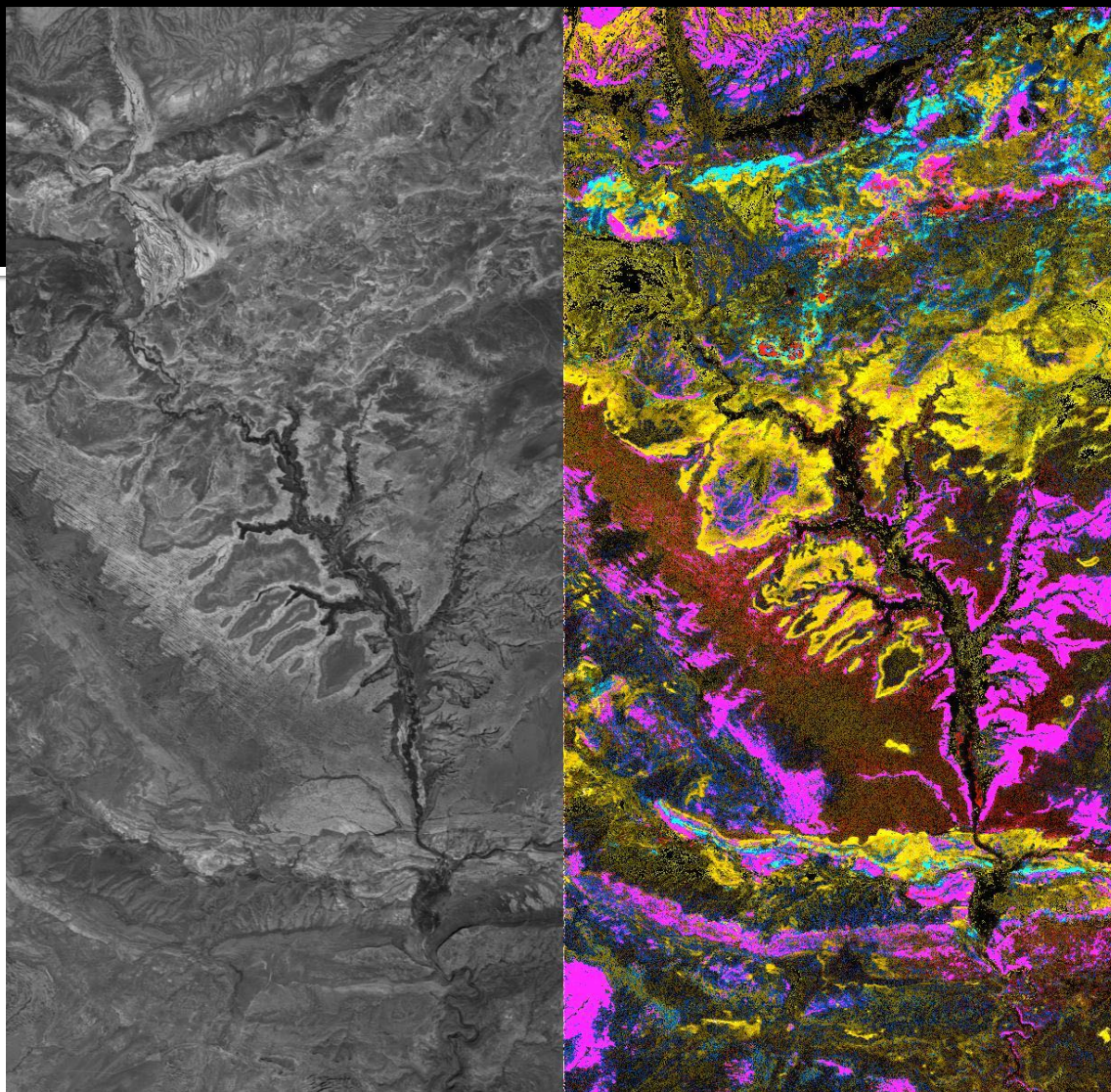
Bayesian
update

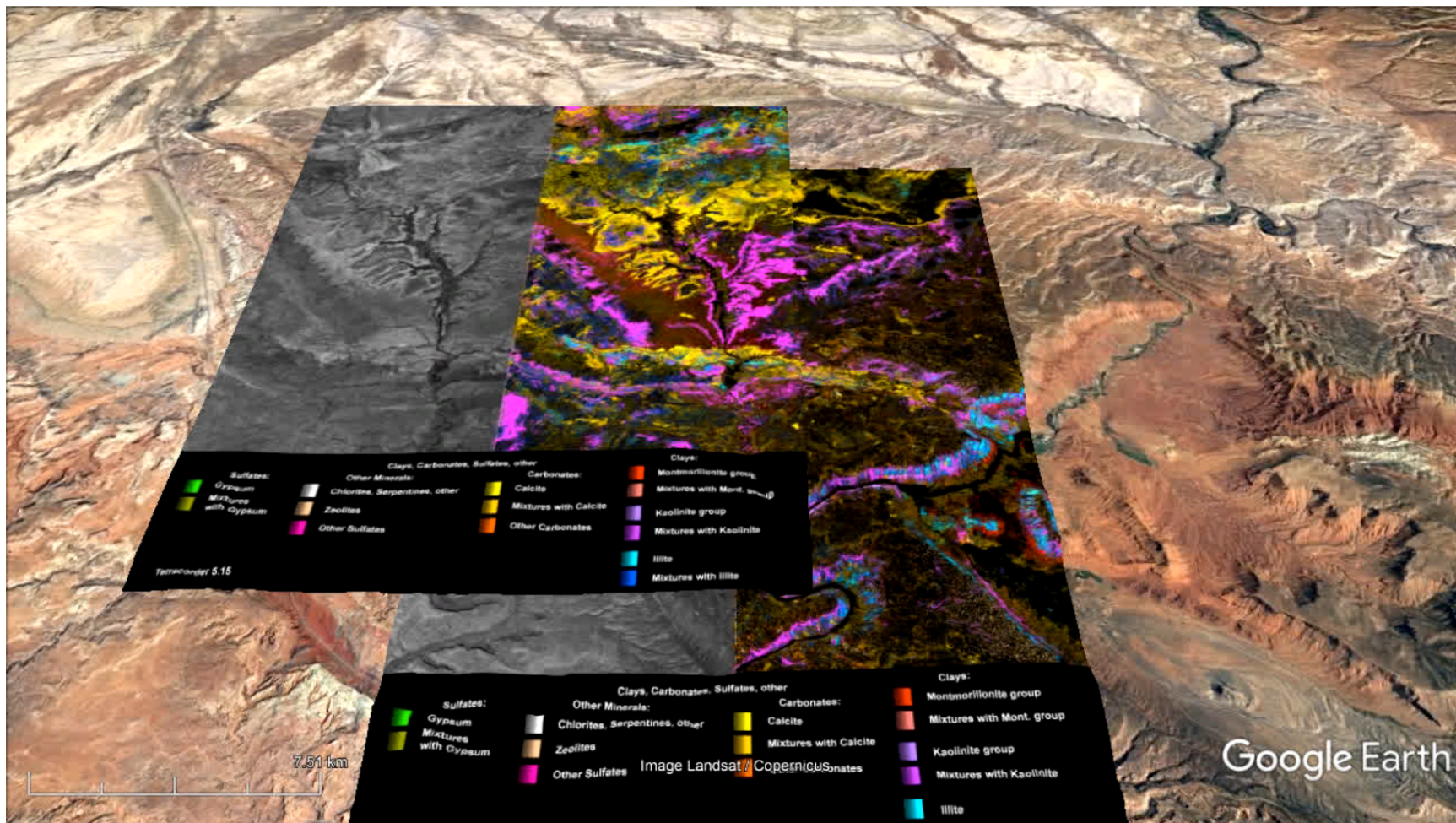
Path /
measurement
plan

Execution

Sensor data







- Two primary advantages to this method:

1. Improved operations efficiency.

- Hypothesis maps communicate the latest objectives simply and intuitively, and define the appropriate behaviors.

2. Improved science return.

- Data acquisition and analysis is not limited by the communications bandwidth

→ Identifies unexpected compositional targets as rover traverses between waypoints

Tools

■ **Hypothesis map:**

- Represents the basis for decision making and reporting undertaken by the robot.
- Describes a set of hypotheses to be explored, and observables that allow these hypotheses to be weighted.
- Rover queries the terrain, certain hypotheses become weighted toward greater likelihood, as others are eliminated.
- In conjunction, the rover populates an n-dimensional parameter space of the observables, allowing it to map the spatial distribution of compositional (spectral) endmembers, which can subsequently be targeted for in-depth analysis.

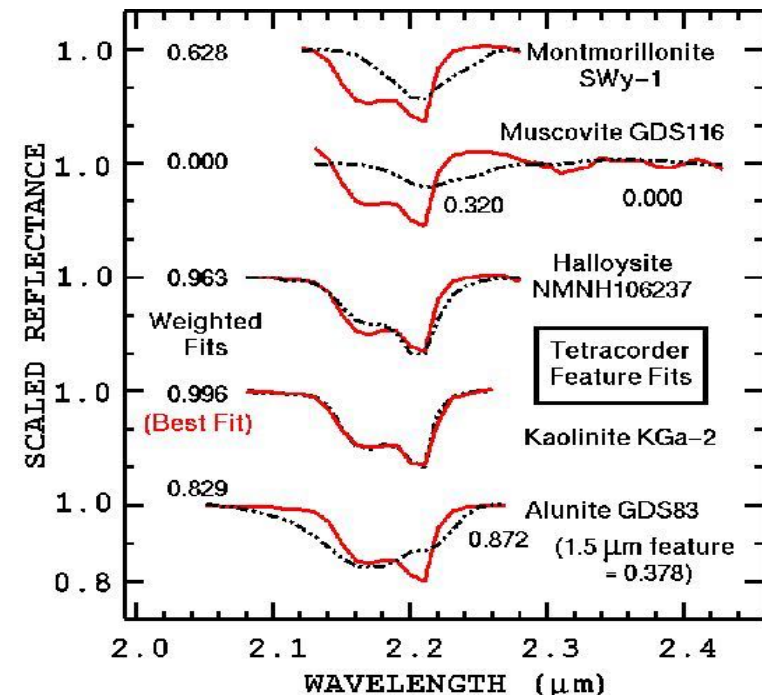
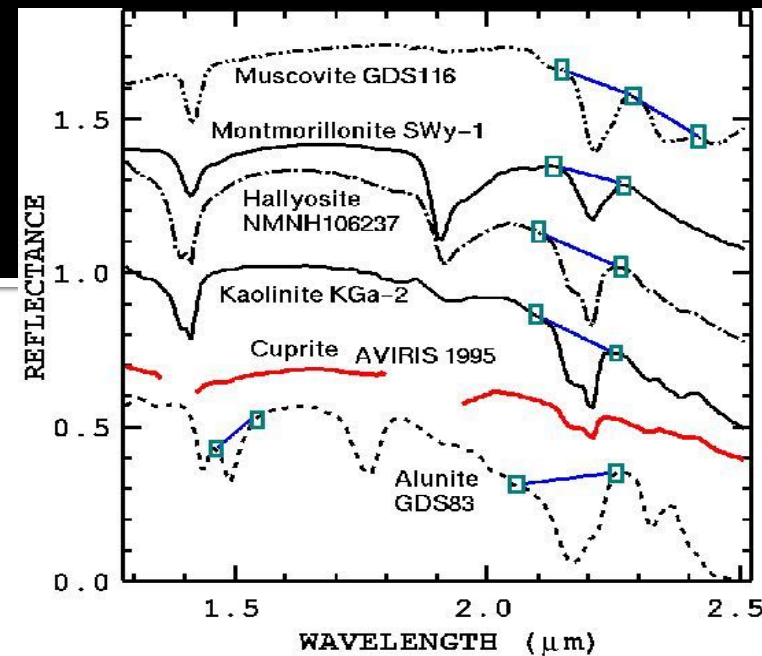
Tools

- **Hypothesis Map (contd)**
- Communication with an operator is performed at points in which the rover has
 - a) a summary of observations of the mapping area,
 - b) identified sample collection sites, or
 - c) performed an observation that cannot be fit into the hypothesis map.

If the latter occurs, the hypothesis map needs to be reformulated, leading to an iterative process between hypothesis formulation and field exploration.

Tools

- **Tetracorder:**
- Automated spectral identification tool based on an “expert system”
- A Tetracorder module operating in real-time on the rover’s computer will allow the rover to constrain mineralogy and address the hypotheses it is tasked to test.



Field Campaign:

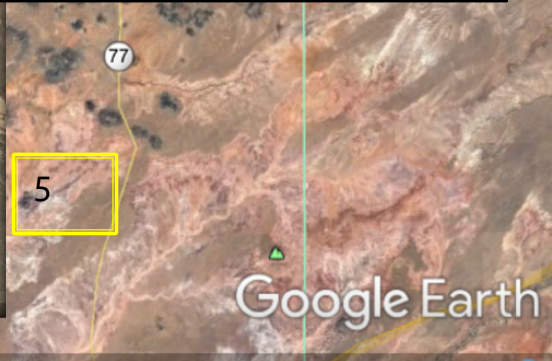
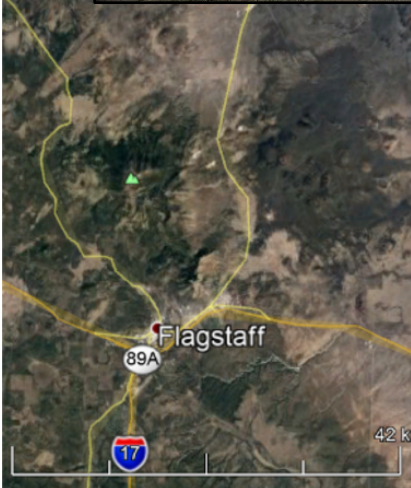
Objective: compare the science yield and operations efficiency of current robotic exploration strategies with that of the semi-autonomous robotic system.

- Use Carnegie Mellon's Zoe rover.
- Multiple instruments:
 - UV, VNIR, Mid-IR spectrometers
 - gamma ray / neutron spectrometer with active interrogation (GNS).
 - Some instruments will be hand-held, simulating contact-science



Field Campaign

- Total 4 weeks over 2 years.
- Fieldwork will be performed at sites containing fine-grained materials.
- Two locations have been chosen:
 1. The Yellow Cat graben in Utah.
 2. The Hopi Volcanic Field in Arizona.



Yellow Cat



Field experiments

- What operational scenarios are we comparing?
 - Standard paradigm (remote-control rover)
 - Astronaut + semi-autonomous rover
 - Autonomous rover
- What parameters are we comparing
 - Science yield
 - Operational efficiency

- In each scenario, will have
 - Remote science team
 - Prepares hypothesis map
 - Defines science operations
 - On-site operations team
 - Manages rover logistics
 - Facilitates contact science
- In the astronaut + rover scenario, will have “astronauts”
 - Two scenarios

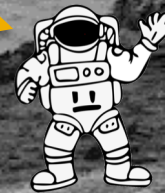
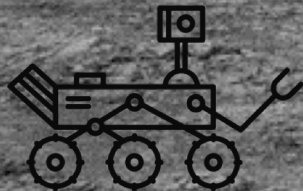
Short sortie



Detailed site information and
sample collection locations (short sorties)

Hypothesis
map

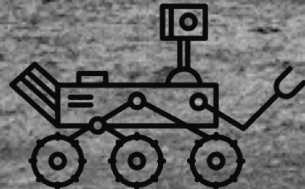
Results



Long sortie

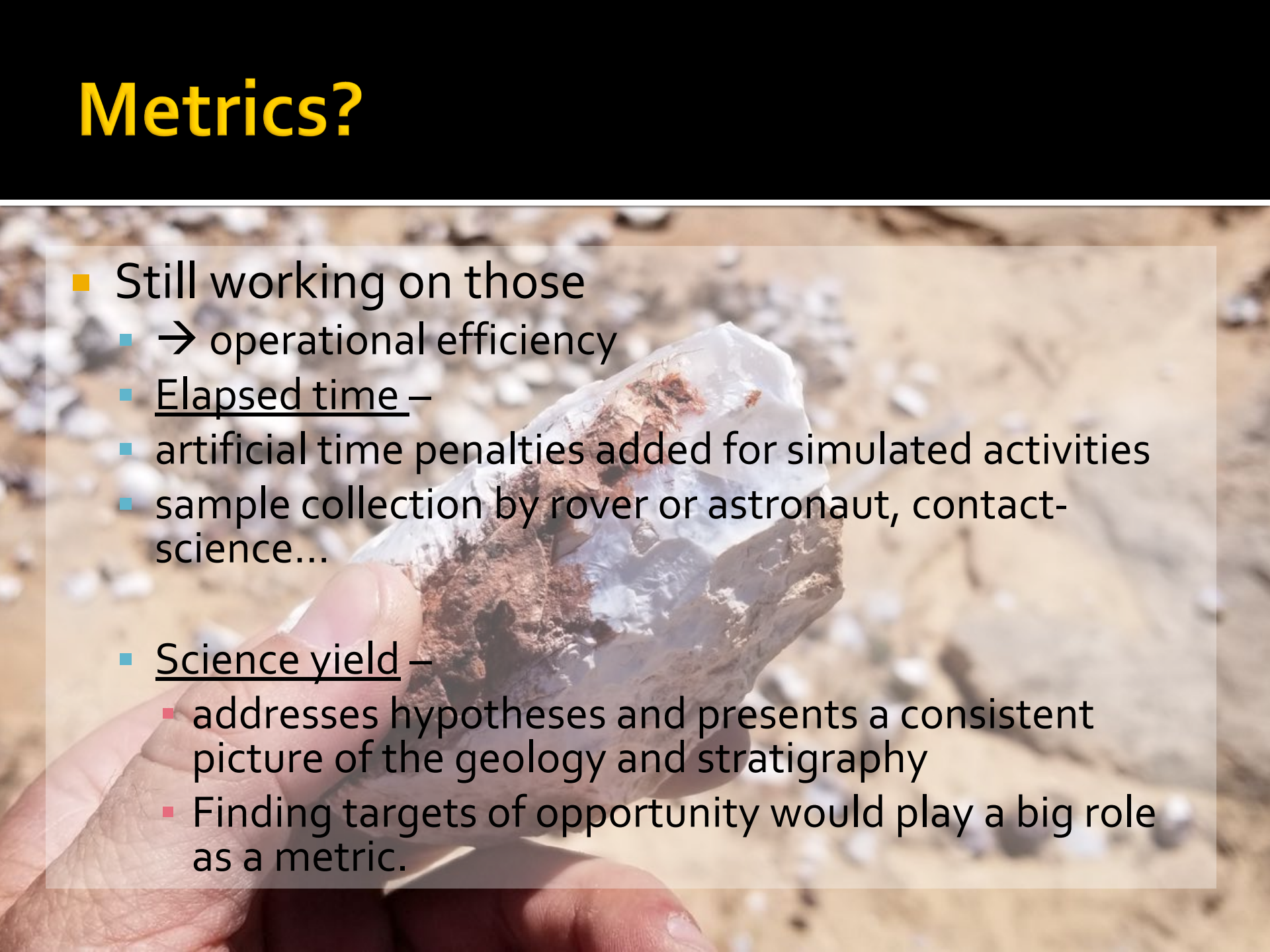


General target locations



Astronaut performs field study, commanding rover to perform specific observations

Metrics?

- 
- Still working on those
 - → operational efficiency
 - Elapsed time –
 - artificial time penalties added for simulated activities
 - sample collection by rover or astronaut, contact-science...
 - Science yield –
 - addresses hypotheses and presents a consistent picture of the geology and stratigraphy
 - Finding targets of opportunity would play a big role as a metric.

- Stay tuned for results at next Year's ESF!

Tools

- **Hypothesis map:**

- Represents the basis for decision making and reporting undertaken by the robot.
- It describes a set of hypotheses to be explored (*e.g.*, the geologic history of a field site), and observables that allow these hypotheses to be weighted (*e.g.*, mineralogical composition, as constrained by spectral measurements).
- As the rover queries the terrain, certain hypotheses become weighted toward greater likelihood, as others are eliminated.
- In conjunction, the rover populates an n-dimensional parameter space of the observables, allowing it to identify the spatial distribution of compositional (spectral) endmembers, which can subsequently be targeted for in-depth analysis.
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